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# Determination and utilization of wind energy potential for Turkey

Cumali İlkiliç *, İsmail Türkbay

*Firat University, Technical Education Faculty, Automotive Department, Elaziğ, Turkey*

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ABSTRACT

In this study, potential and development of wind energy systems in Turkey were studied. The potential and current usage was reviewed. The objective of the study is to investigate the wind energy plants and projects in Turkey. The wind energy potential of various regions and the exploitation of the wind energy were investigated by analyzing wind data measured as hourly time series in the windy locations. The wind data used in this study were taken from Electrical Power Resources Survey and Development Administration (EIEI) for the year 2004. Nurdağı, Karabiga, Datça, Bandırma, Antakya, Mardin, and Kumköy areas were found to be the most suitable areas for wind energy systems by their wind densities; Sinop, Gökçeada, and Siverek are following these areas. The results indicate that the investigated sites have fairly satisfactory wind energy potential for the utilization.



**Contents**



## 1. Introduction

The energy in the wind comes from the sun or wind energy is actually a form of solar energy, because wind is caused by heat from the sun. The sun heats the air around the earth and in some areas the air is heated more than in others. Sun heats every part of the Earth's surface and different Earth's surfaces absorb, retain, reflect and release heat at different rates, and the Earth generally gets warmer during daylight hours and cooler at night. Warm air is lighter than cold air and cooler air moves in the replace the warm air that has risen. As a result, the air above the Earth's surface also warms and cools at different rates. Hot air rises, reducing the atmospheric pressure near the Earth's surface, which draws in cooler air to replace it. That movement of air is what we call wind. These movements of the air form the major winds which blow over the surface of the earth all the time. This happens all around the earth, on the other words, winds result from the fact that the earth's equatorial region receive more solar energy than the polar regions and this sets up large scale convection current in the atmosphere.

Wind energy is known as a renewable and environmental friendly energy source. Utilization of wind energy as an energy source has been growing rapidly in the whole world due to consumption of the limited fossil fuels, environmental pollution and global warming. Wind energy does not have a transportation problem and does not require a high technology to utilize. It has many advantages like cleanliness, low cost, and abundance in everywhere on the world. In order to get benefit from wind energy sources, it must be converted into a different energy type. The kinetic energy in wind is converted into mechanical energy, which is then converted into electrical energy. Wind electricity generation systems convert wind energy into electricity by means of wind turbines. According to the Betz Theorem, the amount of energy obtained by converting wind energy to mechanical energy is proportional to the third power of wind speed [1]. The technology converting wind energy to other energy types are more economical comparing to other conversion systems. Wind is a plentiful source available in the nature which could be utilized by mechanically converting wind power to electrical energy using wind turbine.

* Corresponding author.
*E-mail address:* cilkilic@firat.edu.tr (C. İlkiliç).

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Especially in the last two decades, the wind power potential has been studied in many countries worldwide [2–6].

As environmental concerns have focused attention on the generation of electricity from clean and renewable sources, wind energy has become the world's fastest growing energy source. The growing environmental concern of air quality around the world has created a move to green sources of energy such as wind and solar which provide a pollution-free electricity. The Kyoto Protocol, which regulates the emission of greenhouse-effect gases, has been in effect since February 2005. To achieve even the modest environmental goals of the Kyoto Protocol accords requires the sustained and orderly commercial development of viable renewable energy options. According to Kyoto Protocol renewable energy, which is considered to be a clean energy, can be used to produce electrical energy to reduce air pollutant emissions. It is not enough for governments to support the development of renewable energy technologies. They must also support their commercial application in the country [7,8].

## 2. Operation of wind turbines

Before 20th century, only 10% of the wind energy could be converted into mechanical energy by the wind turbines of the types used then. Today, with modern wind energy conversion systems (WECS), this rate reaches up to 50%. In 1920 and 1926, Albert Betz calculated the optimal geometry of rotor blades, and the maximum wind turbine performance, now called the Betz limit. According to the Betz limit, 59% of the wind power can be converted into a useful energy source [9]. To reach the maximum conversion efficiency, the rotor speed of wind turbine, velocity distribution of wind, and aerodynamics of the wind turbine must be selected optimally. Aerodynamics, electrical transformation system, and control system, which constitute the main elements of the wind turbine, are the structural components of the system. Rotation speed of rotor is lower than the speed required from the generator [10–13].

Wind turbines are energy machines that convert wind power to mechanical energy and then electrical energy sequentially. In a wind turbine mass flows at the entry, between vanes, and at the exit are always constant at any place of the flow volume. This can be stated as:

$$E = \rho A V = \rho_D A_D V_D$$

where $\rho$ (kg/m$^3$) is air density, $A$ (m$^2$) is the area wiped by turbine vanes, $V$ (m/s) is the velocity of the wind, $\rho_D$ (kg/m$^3$) is air density, $A_D$ (m$^2$) is the area wiped by rotor, and $V_D$ (m/s) is the velocity behind the propeller.

Wind energy, which is a renewable energy source, is inexhaustible, clean and free. Renewable energy sources, especially wind energy, offer many environmental and economical benefits in contrast to fossil energy sources. People have been using the wind energy since ancient times for grind the grains and pumping the water. They have used the wind energy to produce electricity effectively for over the last two or three decades by means of modern wind turbines [14–18]. Since then, wind energy is widely used to produce electricity in many countries, such as European countries, United States, Pacific countries, and India. Total wind power installed on the world that is equivalent to 74% of the worldwide wind energy generating capacity, is 115,254 MW at the beginning of 2009. It is expected that the installed capacity on the world will have reached 181,000 MW by the end of 2010 [19].

## 3. Wind energy potential of Turkey

Turkey is located between Europe and Asia like a bridge and surrounded by seas around three sides. Turkey has no large fossil fuel and natural gas reserves, because Turkey is an energy importing country and domestic fossil fuels are limited and the economical condition of the country is not good, almost all of the petroleum and natural gas needed is imported. Energy consumption is increasing parallel to the technological development in the any country. Turkey has been facing continual energy crises because of the difficulty to meet the energy demand. Electricity is produced by hydro power plants and thermal power plants consuming fossil fuels in Turkey. Hydro electricity production has showed decreases as a result of dry weathers in latest years. Wind energy, consequently, which is a renewable energy source, is also among the items that must be investigated very seriously. The present study shows that there is an important potential to use renewable energy, especially wind energy seem to be the most interesting domestic and clean energy sources for Turkey.

In Turkey, it is possible to see a few private sector companies are investing on energy production with wind power lately. Due to legal restrictions, in order to produce electricity by wind turbines, it is necessary to get permission from the Ministry of Energy. The machinery used in WECSs is generally imported since Turkey has no industry on manufacturing these systems. At regions having high wind energy potential, supplying energy for agricultural area like irrigating systems and domestic use in farms can be prior

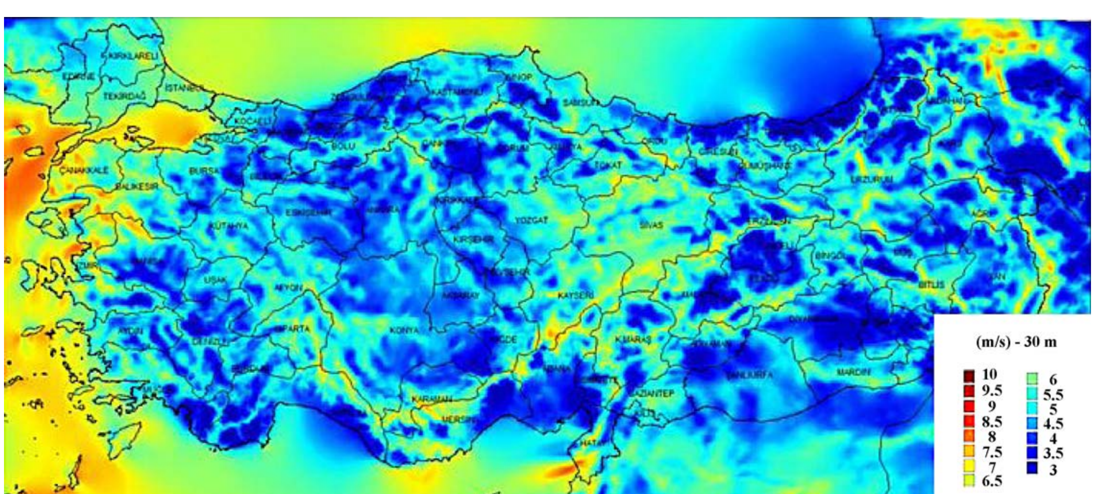



**Fig. 1.** Scattering of wind velocity in 30 m high.

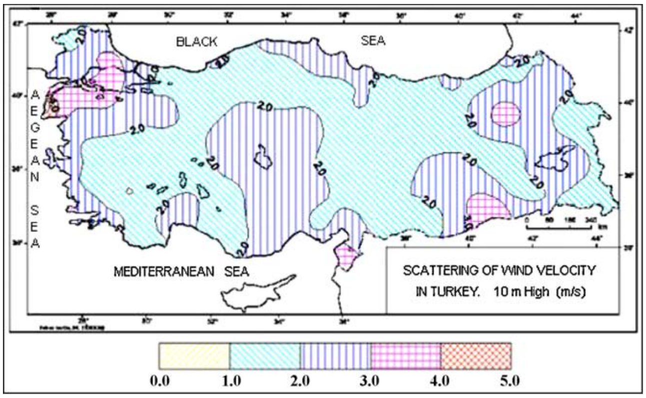



**Fig. 2.** Scattering of wind velocity in10 m high.

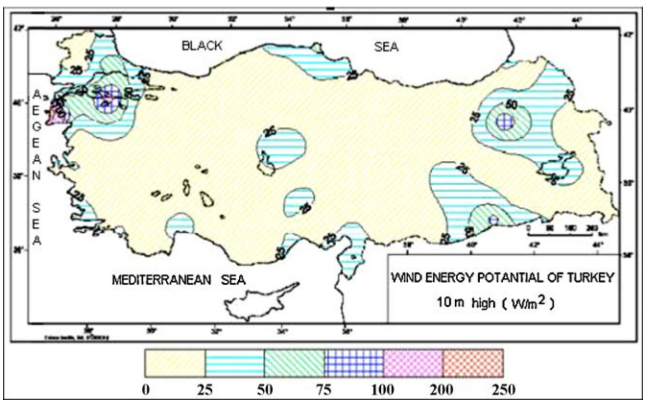



**Fig. 3.** Scattering of wind energy potential in10 m high.

advantages. Output can be satisfactory since the need of energy is quite low at rural areas and the connection lines are expensive to install. Considering the simplicity and the smaller size of wind energy systems, they are economically feasible to install and run. For the areas that need small amounts of energy, energy production and supply can be overcame with smaller investment.

Fig. 1 shows the wind speed scattering in 30 m high, and Figs. 2 and 3 show the wind speed and power densities scattering in 10 m high in Turkey [20]. Compared to seven regions of the country, wind power densities are seemed to be higher at Marmara, Aegean and South-East Anatolia. Wind speeds are therefore higher at these three regions. Along with the mean values of the regions, some focal wind potentials within these regions are listed in Table 1 [21].

According to the data of the General Directorate of State Meteorological Studies, Turkey's annual mean wind speed is 2.58 m/s and wind power density is 25.82 W/m$^2$. The results are summarized in Table 1 at regional base.

**Table 1**
Wind energy potential of Turkey over various regions.

| Region | Annual average wind speed (m/s) | Annual average wind density (W/m$^2$) |
|---|---|---|
| Marmara region | 3.29 | 51.91 |
| Aegean region | 2.65 | 23.47 |
| Mediterranean region | 2.45 | 21.36 |
| Middle Anatolia region | 2.46 | 20.14 |
| Kara Deniz Bölgesi | 2.38 | 21.31 |
| Eastern Anatolia region | 2.12 | 13.19 |
| South-Eastern Anatolia region | 2.69 | 29.33 |
| Average | 2.58 | 25.82 |

Turkey has an important wind energy potential especially in the Marmara region, the Aegean region, coasts of western and southern Anatolia. Wind data at 10 m height above the ground level related to the selected site were taken from EIE (Electrical Power Resources Survey and Development Administration) for the year 2001.

Studies on determining wind energy potentials of promising areas are gaining importance. At first stage, Wind Energy Observatories were established in some promising places like Akhisar, Bababurnu, Bandırma, Belen, Datça, Foça, Gelibolu, Gökçeada, Kocadağ and Sinop and the mean values of wind speeds were calculated at monthly base [Table 2]. Measurements were generally taken at 10–30 m altitudes from the ground with an interval of 10–60 min. Therefore at the areas with sufficient wind speed and densities, great economical benefits can be obtained by establishing wind energy systems [22].

Wind speed varies throughout Turkey from season to season. Monthly mean wind speed variations for overall year are presented in Table 2. The trends of the monthly means for the year are similar for the acquisition station. For the overall year, the mean wind speeds are above 6.46 m/s from January to December. The maximum monthly mean wind speed of 12.0 m/s arises in December, while the minimum of 6.1 m/s occurs in September for Bandırma. In Turkey, the higher heating demand also occurs from November to April, which can be grouped as the Cold Season. The wind energy may be applied as a supplement to the current gas or electricity heating. In Belen, Kocadağ, the wind blows more from April through October than it does in the winter. This is because of the extreme heating of the Aegean region during the summer months. The hot air over the land rises, and the cooler, denser air above the Aegean Sea rushes through the Aegean region mountain pass to take its place. These seasonal variations are a good match for the electricity demands of the regions. In sea coasts, people use more electricity during the summer for air conditioning. In Eastern and South-Eastern Anatolia region, people consume more electricity during the winter months for heating.

In case of present wind speeds to be used, most of the systems are needed to be installed in the areas with high wind potentials. Although the best places are seen as Marmara and Mediterranean coasts, Bandırma and Belen have rich air currents but varying monthly, for example wind speeds from January to September are at a satisfactory level but from September to January they are lower. The seasonal variations of wind speeds in these areas seem to be at larger scales.

After this investigation, many places of the country were seen to have potentials suitable for wind energy systems. There have been many researches to prove that electricity can be produced by wind energy in many areas like Bandırma, Antakya, Kumköy, Sinop, Mardin, Siverek, Gökçeada, Çorlu, and Çanakkale. The most promising places were seen as South coasts of Marmara Sea, Mediterranean coasts, and Mardin and Siverek of South-East Anatolia.

Wind speeds of some points in these areas are 6.82 m/s in Nurdağı, 6.53 m/s in Karabiga, 5.95 m/s in Datça, and 4.2 and 4 m/s in Mardin and Siverek, respectively. Turkey has rich wind power potentials in many areas. According to the reports of State Electrical Studies Board, wind energy potential of Turkey is estimated as around 120 billion kWh. Studies have showed that total wind energy potential of Turkey is higher than its present thermal and hydraulic energy production. Three sides of Turkey are surrounded by seas, therefore it has windy costs. Modern wind mills can be installed near the coasts, on the hills, and at the openings of valleys through the sea for small or medium sized power production systems. These systems can help large amount of petroleum and energy savings.

**Table 2**
Monthly and annual mean wind speeds (m/s) from wind data acquisition station of EIE.

| Station | J | F | M | A | M | J | J | A | S | O | N | D | Mean |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Akhisar | 5.2 | 6.2 | 2.7 | 2.7 | 4.3 | 5.4 | 8.7 | 9.0 | 5.0 | 7.1 | 5.6 | 8.3 | 5.85 |
| Bababurnu | 6.0 | 6.0 | 5.9 | 6.0 | 3.0 | 5.3 | 6.2 | 6.4 | 4.5 | 5.7 | 5.9 | 8.2 | 5.75 |
| Bandırma | – | – | 8.1 | 6.6 | 6.5 | 6.8 | 8.2 | 9.6 | 6.1 | 8.4 | 8.1 | 12.0 | 8.04 |
| Belen | 4.8 | 4.9 | 5.4 | 6.0 | 5.0 | 9.3 | 11.5 | 10.3 | 8.2 | 5.3 | 5.6 | 5.8 | 7.41 |
| Datça | 4.6 | 5.1 | 4.7 | 4.5 | 6.5 | 5.6 | 8.0 | 9.9 | 6.2 | 5.5 | 5.3 | 5.4 | 5.90 |
| Foça | 5.6 | 5.5 | 5.6 | 5.3 | 4.8 | 5.5 | 5.8 | 6.3 | 4.7 | 5.8 | 6.0 | 7.4 | 5.70 |
| Gelibolu | 7.4 | 6.7 | 8.3 | 6.0 | 5.2 | 5.8 | 5.7 | 7.6 | 5.7 | 7.4 | 7.0 | 9.1 | 6.80 |
| Gökçeada | 7.7 | 6.9 | 8.1 | 6.7 | 5.3 | 5.9 | 6.2 | 7.8 | 5.7 | 7.5 | 7.6 | 10.8 | 7.20 |
| Kocadağ | 8.0 | 7.7 | 8.0 | 7.0 | 7.0 | 8.6 | 8.6 | 6.5 | 7.2 | 5.3 | 7.1 | – | 7.36 |
| Sinop | 3.9 | 4.2 | 4.9 | 4.7 | 4.5 | 4.8 | 4.4 | 4.1 | – | – | 5.3 | 5.2 | 4.60 |

In the 1970s, oil shortages pushed the development of alternative energy sources. In the 1990s, the push came from a renewed concern for the environment in response to scientific studies indicating potential changes to the global climate if the use of fossil fuels continues to increase. Wind energy is an economical power resource in many areas of the country. Wind is a clean fuel; wind farms produce no air or water pollution because no fuel is burned. Growing concern about emissions from fossil fuel generation, increased government support, and higher costs for fossil fuels (especially natural gas and coal) have helped wind power capacity in the United States grow substantially over the last 10 years.

**Table 3**
Wind projects in Turkey in 2009.

| Location | Company | Production date | Turbine manufacturer | Installed capacity (MW) | Number of turbine and capacity |
|---|---|---|---|---|---|
| *Wind power plants under production energy* | | | | | |
| İzmir-Çeşme | Alize A.S | 1998 | Enercon | 1.50 | 3 × 500 kW |
| İzmir-Çeşme | Güçbirliği A.S | 1998 | Vestas | 7.20 | 12 × 600 kW |
| Çanakkale-Bozcaada | Bores A.S | 2000 | Enercon | 10.20 | 17 × 600 kW |
| İstanbul-Hadımköy | Sunjüt A.S | 2003 | Enercon | 1.20 | 2 × 600 kW |
| Balıkesir-Bandırma | Bares A.S | 2006 | GE | 30.00 | 20 × 1.500 kW |
| İstanbul-Silivri | Ertürk A.S | 2006 | Vestas | 0.85 | 1 × 850 kW |
| İzmir-Çeşme | Mare A.S | 2007 | Enercon | 39.20 | 9 × 800 kW |
| Manisa-Akhisar | Deniz A.S | 2007 | Vestas | 10.80 | 6 × 1.800 kW |
| Çanakkale-İntepe | Anemon A.S | 2007 | Enercon | 30.40 | 38 × 800 kW |
| Çanakkale-Gelibolu | Doğal A.S | 2007 | Enercon | 14.90 | 13 × 800 kW + 5 × 900 kW |
| Hatay-Samandağ | Deniz A.S | 2008 | Vestas | 30.00 | 15 × 2.000 kW |
| Manisa-Sayalar | Doğal A.S | 2008 | Enercon | 30.60 | 38 × 800 kW |
| İzmir-Aliağa | İnnores A.S | 2008 | Norde | 42.50 | 17 × 2.500 kW |
| İstanbul-GOP | Lodos A.S | 2008 | Enercon | 24.00 | 12 × 2.000 kW |
| İstanbul-Çatalca | Ertürk A.S | 2008 | Vestas | 60.00 | 20 × 3.000 kW |
| Balıkesir-Şamlı | Baki A.S | 2008 | Vestas | 90.00 | 38 × 3.000 kW |
| Muğla-Datça | Dares A.S | 2008 | Enercon | 10.00 | 27 × 800 kW + 8 × 900 kW |
| Capacity under operation | | | | 433.35 | |
| *Wind power plant under construction* | | | | | |
| Aydın-Didim | Ayen A.S | 2009 | Suzlon | 31.50 | 2.100 kW |
| Hatay-Samandağ | Ezse Ltd. Şti. | 2009 | Nordex | 35.10 | 900 kW |
| Hatay-Samandağ | Ezse Ltd. Şti. | 2009 | Nordex | 22.50 | 2.500 kW |
| Osmaniye-Bahçe | Rotor A.S | 2009 | GE | 135.00 | 54 × 2.500 kW |
| İzmir-Çeşme | Mazı-3 Res. A.S | 2009 | Nordex | 22.50 | 9 × 2500 kW |
| İzmir-Çeşme | Kores A.S | 2009 | Nordex | 15.00 | 1 × 2.500 kW |
| Manisa-Soma | Soma A.S | 2009 | Enercon | 140.80 | 176 × 800 kW |
| Capacity under construction | | | | 142.80 | |
| *Projects with a turbine supply contract* | | | | | |
| Balıkesir-Susurluk | Alize A.S | 2009 | Enercon | 19.00 | 17 × 800 kW and 6 × 900 kW |
| Balıkesir-Bandırma | Borasco A.S | 2009 | Vestas | 45.00 | 15 × 3000 kW |
| Tekirdağ-Şarköy | Alize A.S | 2009 | Enercon | 28.80 | 14 × 2000 kW and 1 × 800 kW |
| Balıkesir-Havran | Alize A.S | 2009 | Enercon | 16.00 | 8 × 2000 kW |
| Çanakkale-Ezine | Alize A.S | 2009 | Enercon | 20.80 | 10 × 2000 kW and 1 × 800 kW |
| Hatay-Belen | Belen A.S | 2009 | Vestas | 30.00 | 10 × 3000 kW |
| Manisa-Kırkağaç | Alize A.S | 2009 | Enercon | 25.60 | 32 × 800 kW |
| Edirne-Enez | Boreas A.S | 2009 | Nordex | 15.00 | |
| İzmir-Aliağa | Doruk A.S | 2009 | Enercon | 30.00 | 15 × 2.000 kW |
| İzmir-Aliağa | Yapısan İnş. Elk. San. Tic. A.S | 2009 | Nordex | 90.00 | 36 × 2500 kW |
| İzmir-Aliağa | Doğal A.S | 2010 | Enercon | 30.00 | 15 × 2000 kW |
| İzmir-Foça | Doğal A.S | 2010 | Enercon | 30.00 | 15 × 2000 kW |
| Balıkesir-Kepsut | Poyraz A.S | 2010 | Enercon | 54.90 | 61 × 900 kW |
| Manisa-Soma-Kırkağaç | Bilgin E. Ü. A.S | 2010 | Nordex | 90.00 | 36 × 2500 kW |
| Balıkesir-Kepsut | Bares E. Ü. A.S | 2010 | Nordex | 142.50 | 57 × 2500 kW |
| Capacity projects with a turbine supply contract | | | | 1070.00 | |
| General total | | | | 1546.15 | |

The most serious environmental drawbacks to wind machines may be their negative effect on wild bird populations and the visual impact on the landscape. To some, the glistening blades of windmills on the horizon are an eyesore; to others, they're a beautiful alternative to conventional power plants.

## 4. Current status of wind energy usage in Turkey

In Turkey, wind electricity conversion system was set up with a nominal 55 kW power in Çeşme. Then the larger scale wind electricity was set up in Germiyan in Çeşme, Turkey. The biggest available wind energy power plant in Turkey is the Baki (Balıkesir-Şamlı) with 90.00 MW power. It was constructed in 2008 and uses 30 turbines, and each turbine has 3000 kW power. The current production wind energy projects in Turkey 433.35 MW. This production will be 1503.35 MW with capacity under construction and the projects with a turbine supply contract at the end of 2010. The detailed information about capacity under operation, capacity under construction and projects with a turbine supply contract has been presented in Table 3 [23].

The development of modern Turkish wind power engineering began from 2006 when the 20 wind turbines of 1500 kW each began to operate at Bandırma, Balıkesir. Then, the wind farm consisting of 1 turbines of 850 kW was constructed at Silivri, İstanbul in 2006, and the other wind farm with total-installed capacity of 39.2 MW started to operate from 2007 at Çeşme, İzmir. In the same year, it was constructed three wind farm that they has total 56.10 MW at Akhisar, İntepe and Gelibolu, respectively. In 2008, seven wind power plants began to produce electrical energy from wind with they have 287.1 MW power capacity. They are located Samandağı, Sayalar, Aliağa, Gaziosmanpaşa, Çatalca, Şamlı and Datça, respectively. At the end of 2008, total-installed capacity was 433.35 MW in Turkey. This capacity will reach to 835.75 MW at the end of 2009 with seven wind power plants. In addition, wind installed capacity in Turkey will be reached to 1503.35 MW by the end of 2010.

## 5. Conclusion

In this study, assessments of the wind characteristics and wind power potential and wind energy conversion systems in Turkey for the year 2009 were investigated. This research about wind energy shows that wind power is one of the most important energy sources for Turkey. Turkey has a considerably high level of wind energy, resources that can be utilized to satisfy a part of the total energy demand in the country. The latest applications have shown that wind energy sources in Turkey are a promising alternative energy. Wind speed and energy maps of Turkey have been presented and the potential areas are identified with the emphasis on their significance. In general, potential wind energy areas in Turkey lie in northern parts and the Northwestern parts, at locations along the Aegean sea and Marmara sea coast. Aegean, Marmara, South-East Anatolia and East-Mediterranean regions of Turkey are generally seen as promising of higher wind power potential compared to other parts of Turkey. However, the most single locations are in Gokçeada Island and Bandırma area, these are all along the sea coasts. Other potential areas are along the middle Black Sea region, eastern Mediterranean areas and South-Eastern Anatolia region (Mardin and Siverek locations), among the inland areas, Diyarbakır in South-Eastern Anatolia provides a significant potential area. Turkey, whose wind energy potential is abundant, should be given much more importance in meeting energy demands. In Turkey, the available wind energy power is 433.35 MW by the end of the year 2008. The strong development of wind energy in Turkey is expected to continue in the coming years. After all, it can be concluded that wind energy generation locations in Turkey are all at low altitudes.

1. Wind energy is a clean fuel source, because this energy is fueled by the wind. Wind energy is a clean, emissions-free power generation technology, and it does not pollute the atmosphere like power plants that rely on combustion of fossil fuels, such as coal or natural gas. Wind power also has a positive effect on the quality of the air that we breathe, and the combustion of fossil fuels also produces the gases sulphur dioxide and nitrogen oxide, both serious sources of air pollution. Wind turbines don't produce atmospheric emissions that cause acid rain or greenhouse gasses.
2. Wind energy is a domestic source of energy, produced in Turkey. Wind power will play a particularly important role in Turkey with plentiful of wind energy when the price of crude oil continues to increase in the future. The nation's wind supply is abundant, and cost less to be produced, because fossil fuels pollute environment badly and their sources are not limitless in Turkey. Presently, major share of electricity generation in Turkey is from hydrolic and thermal. Renewable energy sources in Turkey are in abundance, which can fulfill the growing energy demand.
3. The energy demand in Turkey is increasing rapidly, like other developing countries in the world. Continued population growth, and economic and technologic development are driving energy demand faster than Turkey can produce it. Energy is essential to the economic and social development and will improve the quality of living life in Turkey. During the last two decades, the wide expansion of industrial and residential areas has caused a high demand of electrical power. Because of technological and economical growing factors, renewable energy sources do not have wide application either in Turkey or in the world at present.

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